



Accelerated Insertion of Materials – Composites: *a* *Technology Investment Agreement*

Presented at
MMS-OTRC Workshop
“Qualifying New Technology for
Deepwater Oil and Gas Development”
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Also:

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AIM-C Team - Boeing (St. Louis, Seattle, Canoga Park, Philadelphia), Northrop Grumman, Materials Sciences Corporation, Convergent Manufacturing Technologies, Cytec Fiberite, Inc, Massachusetts Institute of Technology, Stanford & NASA (Langley)

The Traditional Process

Why We Test

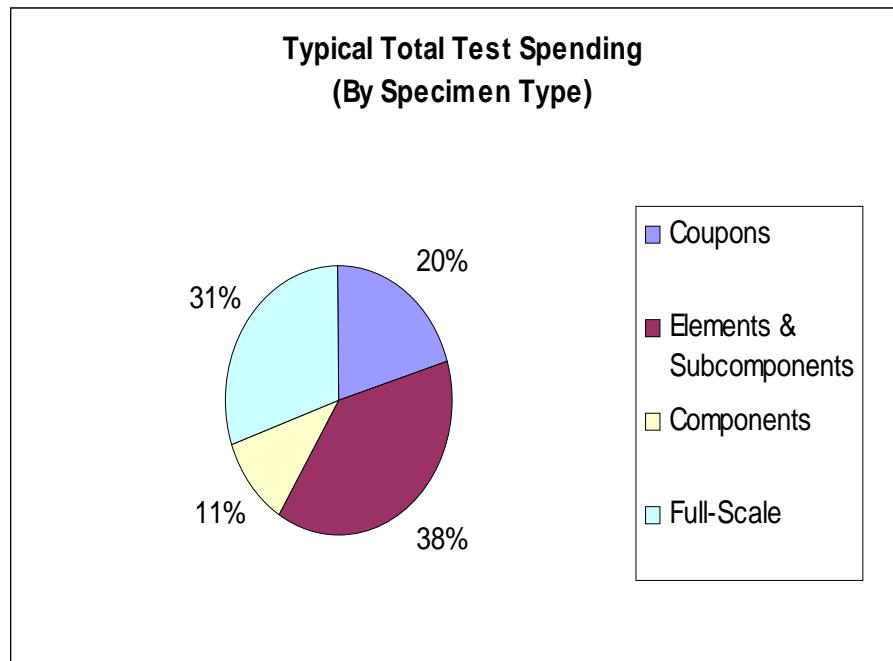
- Using an Un-augmented “Building Block Approach”, a Typical Composites Program Requires 6000 to 10,000* Specimens to:
 - Characterize the Material
 - Develop Design Allowables
 - Select/Develop the Design Concept
 - Calibrate Semi-Empirical Analysis Methods
 - Validate the Design and Analysis

* Ref. F/A -18 and 777 empennage



How Much It Costs

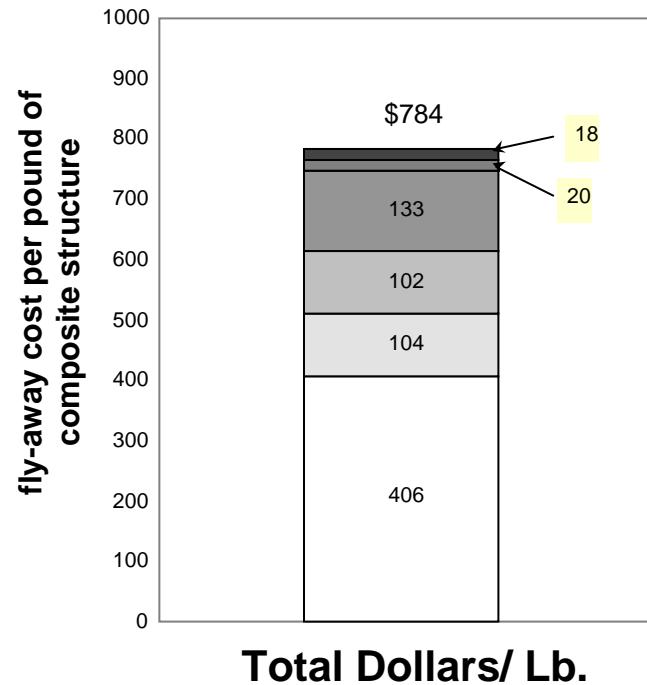
- The Total Cost of Building and Testing These Specimens is between \$50M and \$100M and takes at least several years.
- Despite several very expensive component tests, much of this money and time is spent on the numerous coupons, elements, and subcomponents.



- Specimen types and numbers are averages based on various test plans
 - New composite material specimens only
 - Only 1 full-scale Test Component testing includes items such as fuel box, side-of-body joint, large fittings, etc.
- Fab. And Test Hours/specimen (for each type) based on internal Boeing estimating documents
- Typical Industry Labor Rates
- Fabrication and Test Cost Only –Facilities, Equipment, Material, and Design/Analysis Costs not included

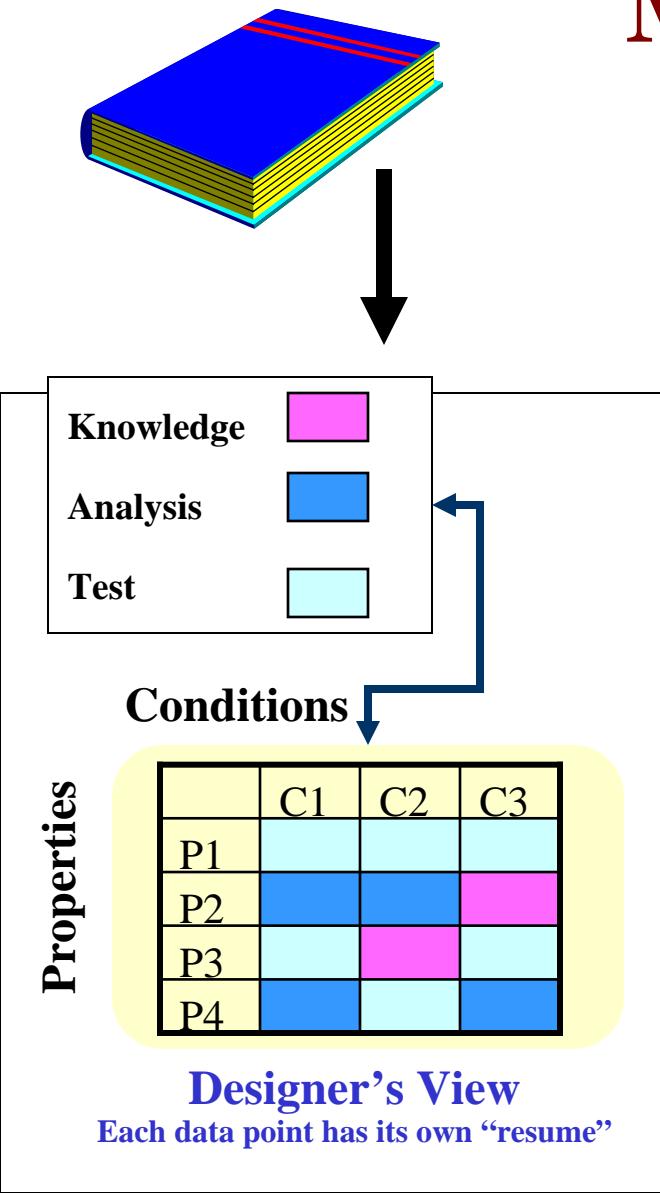
Boeing is the World's Largest Manufacturer of Composite Aerospace Parts

- Tooling Material
- Recurring Tooling Support
- Assembly Tools
- Detail Tools for Composites
- Assembly Labor and Materials
- CFRP Detail Labor and Materials



- 4 Million Pounds Annually
- ~ \$300M Spent on Raw Material
- We Add ~ 5 times to the value
- \$2B Annually Fly Away

Accelerated Insertion of Materials Goals



Transform traditional materials database and qualification practice into an efficient and interactive process fully integrated into the available design tools and design community that retains/improves upon the robustness and reliability of traditional practice.

Use the right source (model, experiment, experience) to fill in the data

AIM Methodology: Criteria for Success

1. Architecture

- Open/controlled (secure/open)
- Platform independent (Intranet vs. Internet)

2. Capabilities – at least 4 capabilities/modules

- Properties – time dependent properties
- Durability/Lifing
- Processing/Manufacturing/Producibility
- Cost

AIM Methodology: Criteria for Success

3. Features/Outputs

- Demonstrate that the methodology reproduces the designer knowledge base
- Demonstrate that “a rogue” process spec will result in a flag by the system
- Demonstrate that a rogue “geometry” results in an “un-producible” flag
- Demonstrate the ability of the system to direct experiment – to direct an experiment to determine a “benchmarking” parameter, or a basic physical quantity. (validation/calibration)



AIM-C Alignment Tool

The Objective of the AIM-C Program is to Provide Concepts, an Approach, and Tools That Can Accelerate the Insertion of Composite Materials Into DoD Products

AIM-C Will Accomplish This Three Ways

Methodology - *We will evaluate the historical roadblocks to effective implementation of composites and offer a process or protocol to eliminate these roadblocks and a strategy to expand the use of the systems and processes developed.*

Product Development - *We will develop a software tool, resident and accessible through the Internet that will allow rapid evaluation of composite materials for various applications.*

Demonstration/Validation - *We will provide a mechanism for acceptance by primary users of the system and validation by those responsible for certification of the applications in which the new materials may be used.*



DESIGN TEAM'S NEEDS

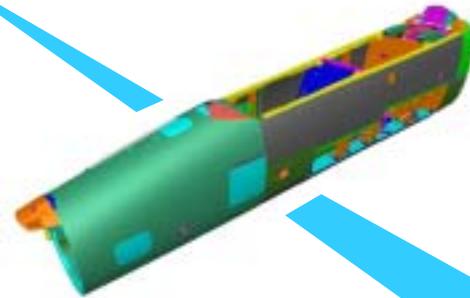
Requirements Flow-Down

Program/Product Level



- Performance
- Life Cycle Cost
- Development and Delivery Schedules
- Risk Posture

Component Level



- Weight, Smoothness, etc.
- Service Environment
- Unique Functionality
- Unit Cost Targets
- Production Concept
- O&S Concepts

Part Level



- Strength and Stiffness
- Temperature
- Geometry Assurance
- Fab and Assembly Concepts
- Damage Tolerance & Repair

Material Choice is Influenced by Higher Level Requirements (and Vice Versa)

DESIGN TEAM'S NEEDS

Requirements are Multi-Disciplined

Structural

- Strength and Stiffness
- Weight
- Service Environment
 - Temperature
 - Moisture
 - Acoustic
 - Chemical
- Fatigue and Corrosion Resistant
- Loads & Allowables
- Certification

Manufacturing

- Recurring Cost, Cycle Time, and Quality
- Use Common Mfg. Equipment and Tooling
- Process Control
- Inspectable
- Machinable
- Automatable
- Impact on Assembly

Supportability

- O&S Cost and Readiness
- Damage Tolerance
- Inspectable on Aircraft
- Repairable
- Maintainable
 - Accessibility
 - Depaint/Repaint
 - Reseal
 - Corrosion Removal
- Logistical Impact

Material & Processes

- Development Cost
- Feasible Processing Temperature and Pressure
- Process Limitations
- Safety/Environmental Impact
- Useful Product Forms
- Raw Material Cost
- Availability
- Consistency

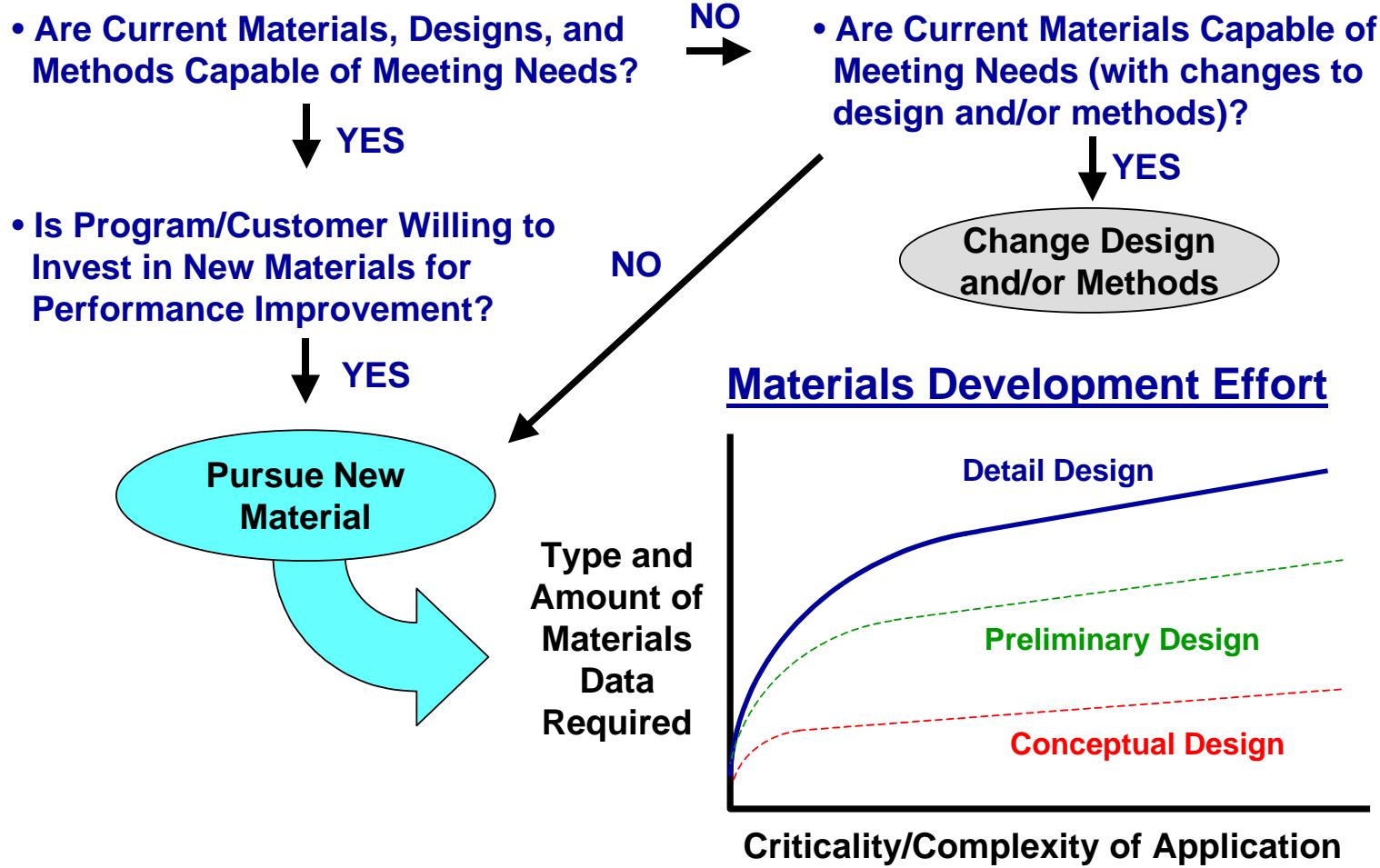
Miscellaneous

- Observables
- EMI/Lightning Strike
- Supplier Base
- Applications History
- Certification Status
 - USN
 - USAF
 - ARMY
 - FAA

Risk in Each Area is Dependent Upon Application's Criticality and Material's Likelihood of Failure

DESIGN TEAM'S NEEDS

Data Drives Decisions



AIM-C Will Validate the Process



**Methodology
That Links an
Accelerated
Process to the
Knowledge
Requirements**

Embedded
In



**Software
That Links the Methodology to
Knowledge, Analysis Tools,
and Test Recommendations**



**Demonstrations
Focused on
Recreating
Existing Data,
Precluding
Persistent
Problems, and
Independent Peer
Assessment**



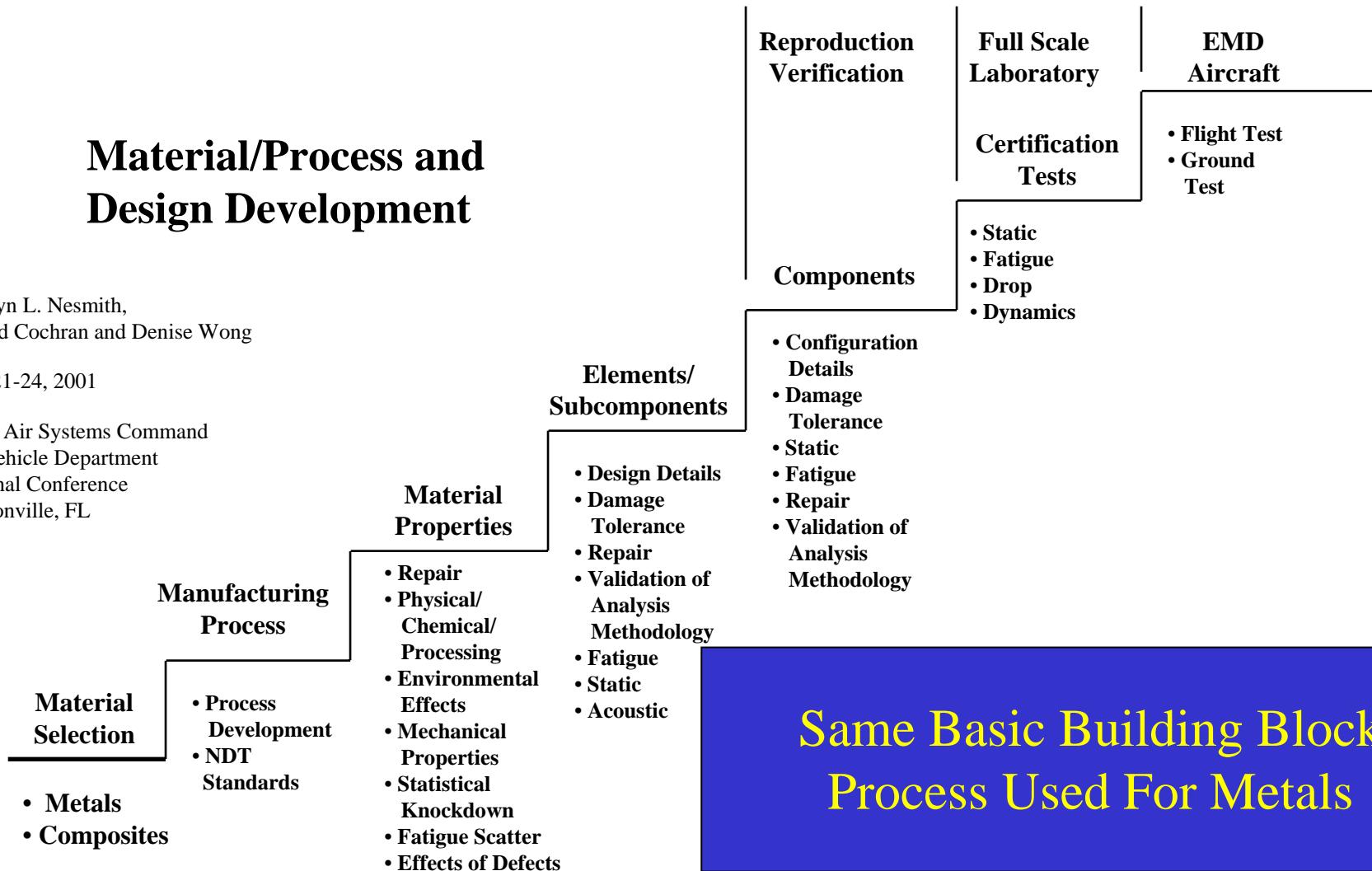
“Building Block” Test Program

Material/Process and Design Development

Kathryn L. Nesmith,
Roland Cochran and Denise Wong

May 21-24, 2001

Naval Air Systems Command
Air Vehicle Department
National Conference
Jacksonville, FL

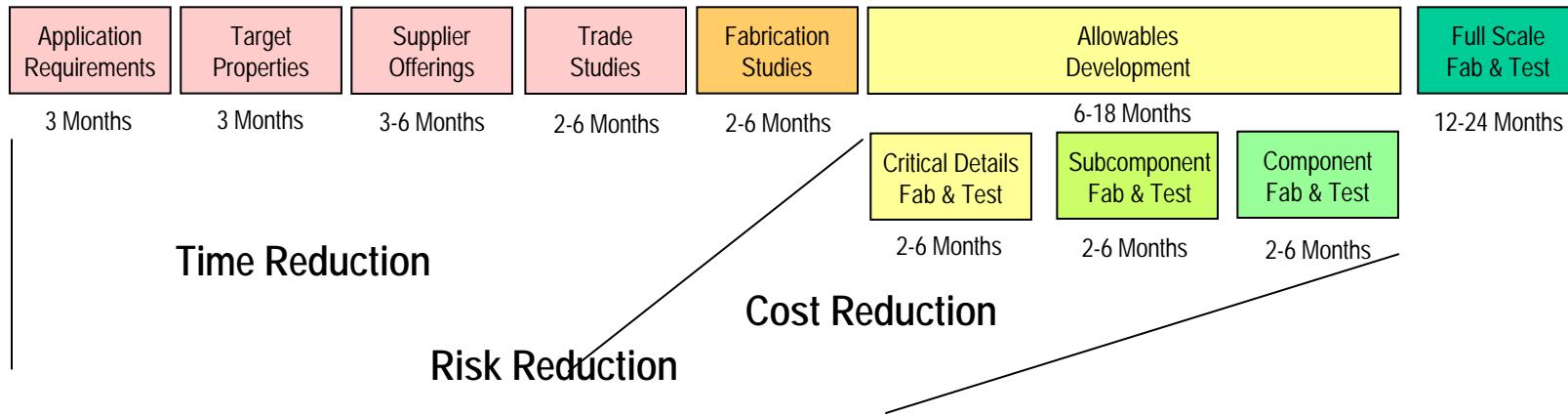


Same Basic Building Block
Process Used For Metals

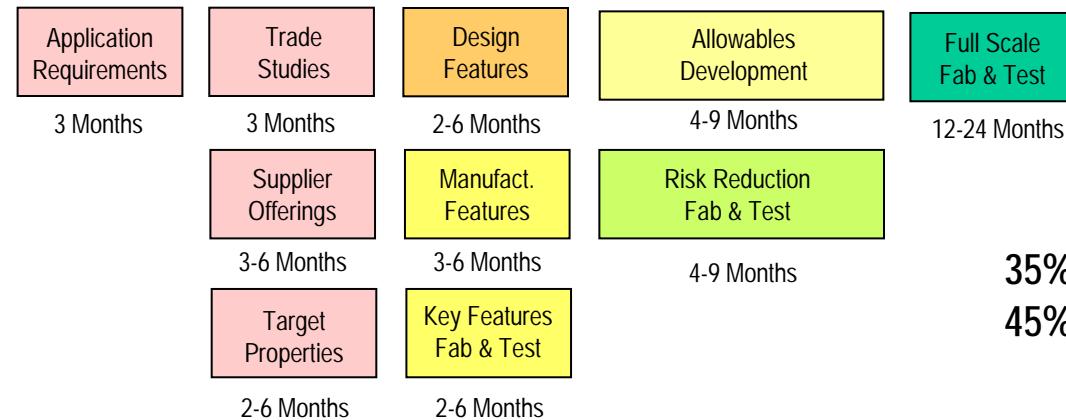


The AIM Process Uses a Team Approach to Drive Rapid Insertion

Conventional Building Block Approach to Certification



The AIM Focused Approach to Certification



35% Reduction in Total Time to Certification
45% Reduction in Time to Risk Reduction

Material Insertion Methodology

Methodology Covers:

- What Needs to be Done?
- When is it Done?
- How is it Done?
- Why is it Done?

Methodology Has to Accommodate:

- Designer Perspective + Others
- Product Certification Requirements
- Material Qualification Requirements
- Multiple Tool Sets
- Testing
- Traceability
- Integration

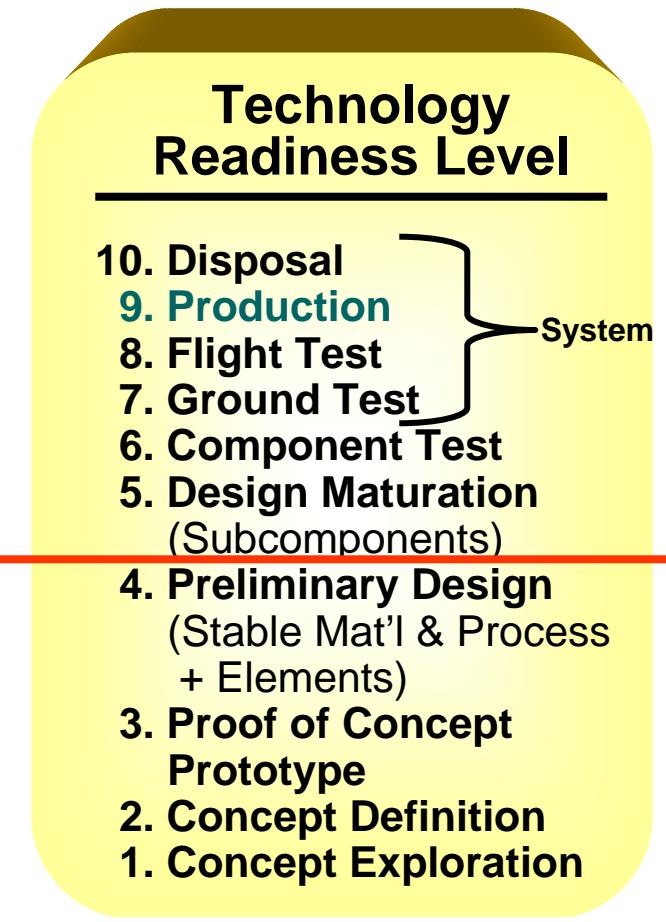
How

Tool Sets:

- Technology Readiness Level (TRL) Definitions/Chart/Worksheet
- (x) Readiness Level (xRL) Definitions/Chart/Worksheet
- Technical Requirements Definitions
- Definitions/Worksheets/Templates
- Physics/Science Based Models
- Math/Statistics Models & Functions
- Heuristic Models
- Relational Data Bases for Information Storage/Retrieval
- Usage Scenarios
- Other

What, When, Why

Methodology – What & When



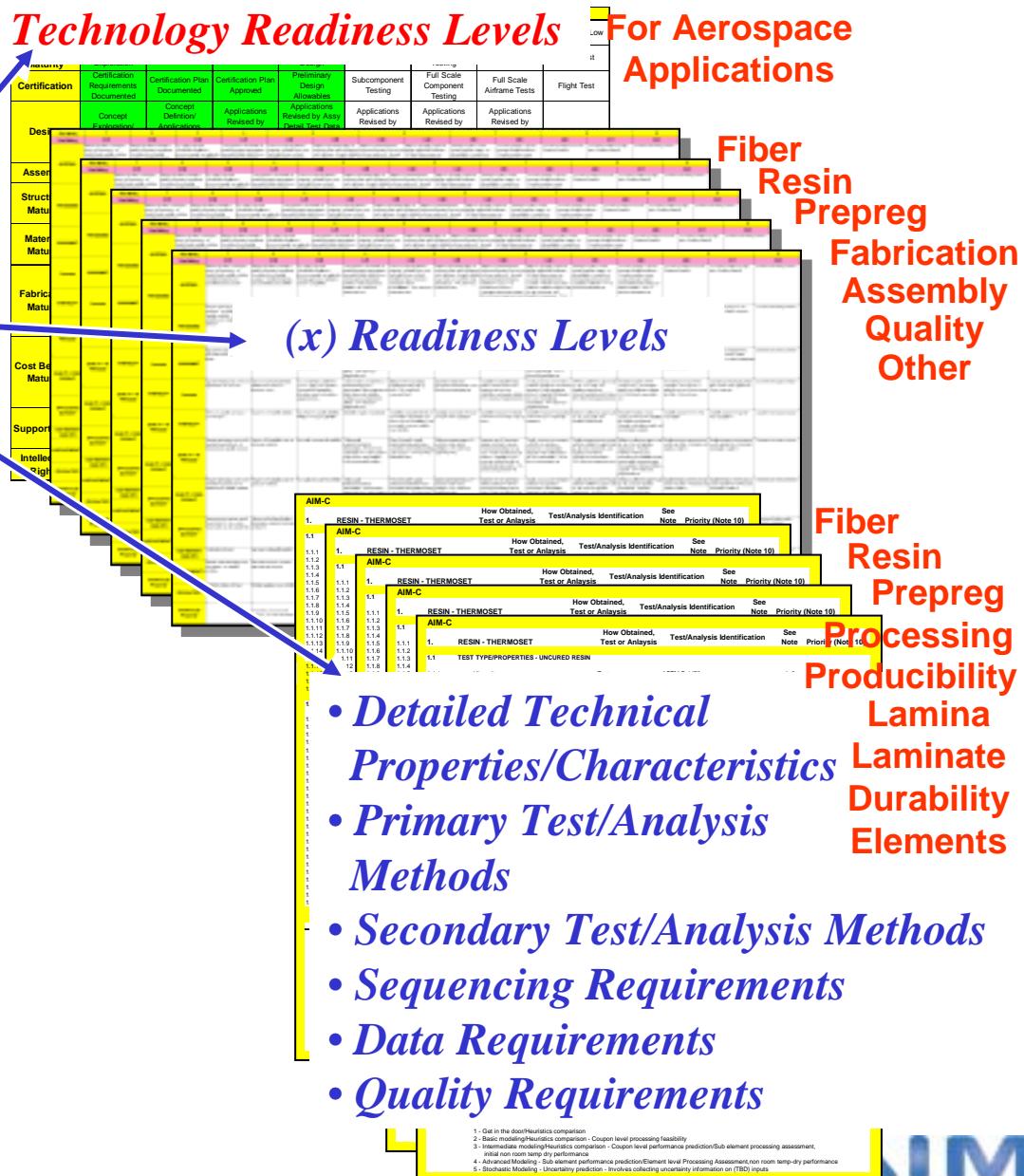
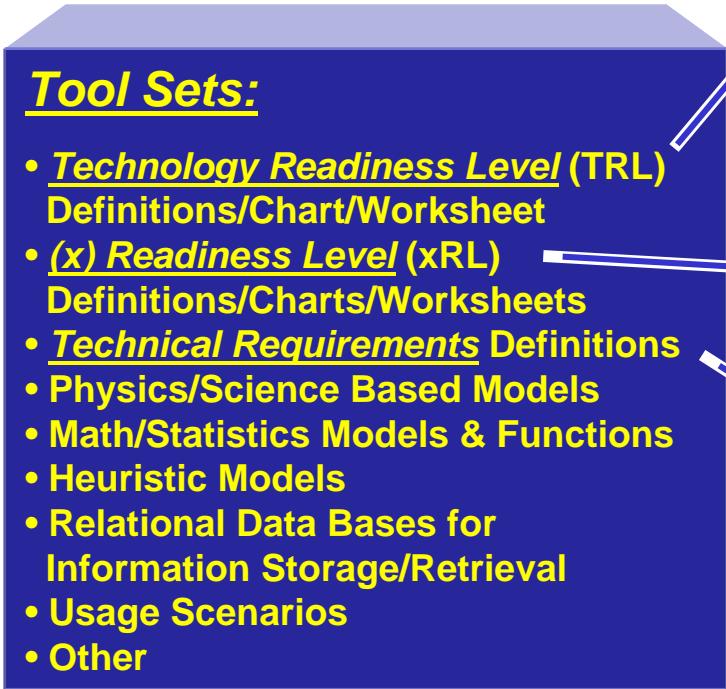


Technology Readiness Levels

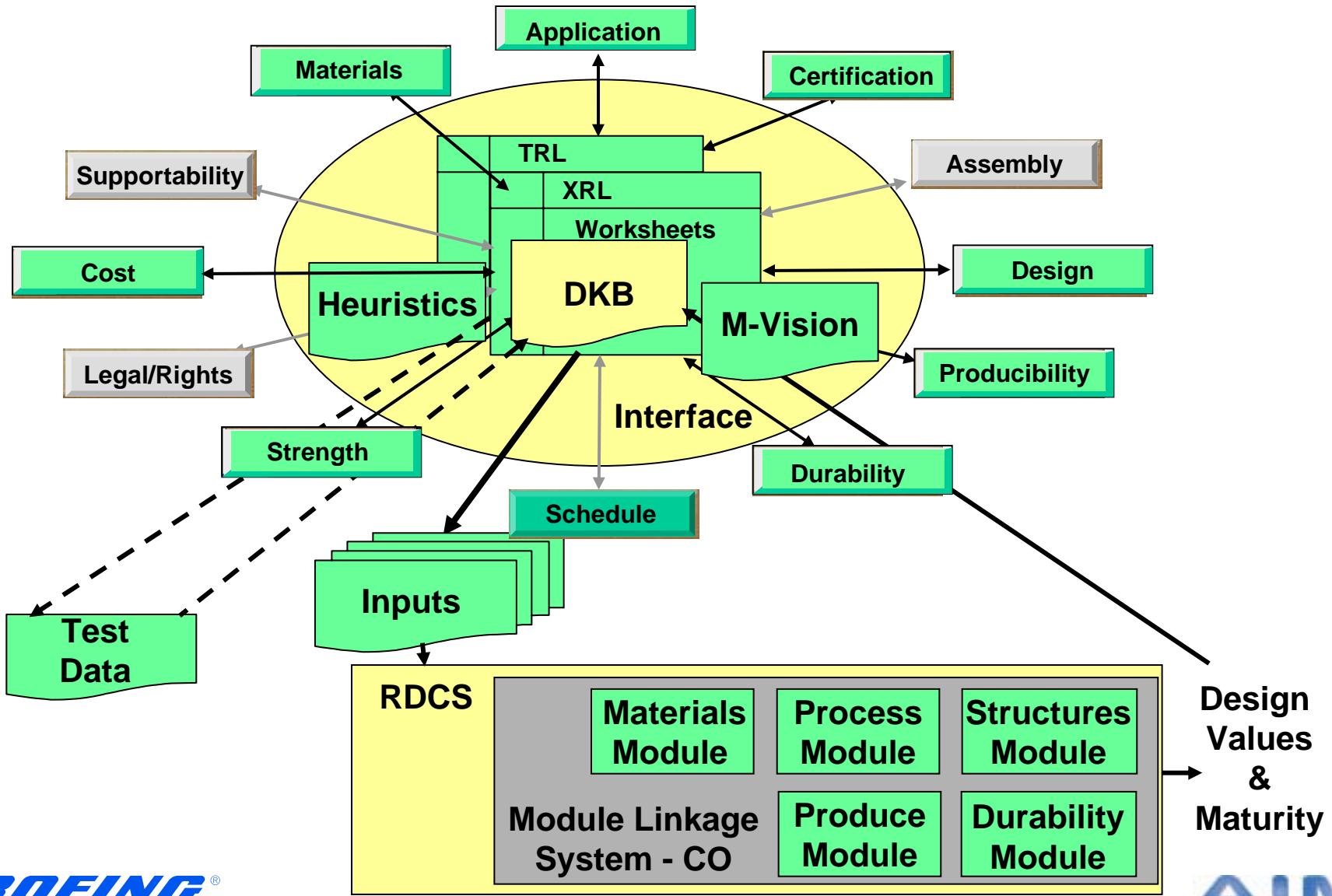


TRL	1	2	3	4	5	6	7	8
Application Risk	Very High	High	High - Med	Med - High	Medium	Med - Low	Low	Low - Very Low
Application Maturity	Concept Exploration	Concept Definition	Proof of Concept	Preliminary Design	Design Maturation	Component Testing	Ground Test	Flight Test
Certification	Certification Requirements Documented	Certification Plan Documented	Certification Plan Approved	Preliminary Design Allowables	Subcomponent Testing	Full Scale Component Testing	Full Scale Airframe Tests	Flight Test
Design	Concept Exploration/ Potential Benefits Predicted	Concept Definition/ Applications Revised by Lamina Data (Coupons)	Applications Revised by Laminate Data (Coupons)/ Design Closure	Applications Revised by Assy Detail Test Data (Elements)/ Preliminary Design	Applications Revised by Subcomponent Test Data/ Design Maturation	Applications Revised by Component Test Data/ Ground Test Plan	Applications Revised by Airframe Ground Tests/ Flight Test Plan	Production Plan
Assembly	Assembly Concept	Assembly Plan Definition	Key Assembly Detail Definitions	Key Assembly Details Tested	Subcomponents Assembled	Components Assembled	Airframe Assembled	Flight Vehicles Assembled
Structures Maturity	Preliminary Properties- Characteristics	Initial Properties Verified by Test	Design Properties Developed	Preliminary Design Allowables	B-Basis Design Allowables	A-Basis Design Allowables		
Materials Maturity	Lab-Prototype Materials	Pilot Production Materials	Pre-Production Materials	Production Materials/ Material Specs			EMD Material Supplied	LRIP Material Supplied
Fabrication Maturity	Unfeatured-Panel Fabrication	Feature Based Generic Small/Subscale Parts Fabricated	Property-Fab Relationships Tested/ Target Application Pilot Production of Generic Full Size Parts	Process Specs/ Effects of Fab Variations Tested/ Elements Fab'd/ Production Representative Parts Fab'd	Subcomponents Fab'd	Full Scale Components Fabricated	EMD Fabrication	Low Rate Initial Production (LRIP)
Cost Benefits Maturity	Cost Benefit Elements ID'd & Projected	ROM Cost Benefit Analysis	Cost Benefit Analysis Reflect Size Lessons Learned	Cost Benefit Analysis Reflect Element and Production Representative Part Lessons Learned	Cost Benefit Analysis Reflect Subcomponent Fab & Assembly Lessons Learned	Cost Benefit Analysis Reflect Component Fab & Assembly Lessons Learned	Cost Benefit Analysis Reflect EMD Lessons Learned	Cost Benefit Analysis Reflect LRIP Lessons Learned
Supportability	Repair Items/Areas Identified	Repair Materials & Processes Identified	Repair Materials & Processes Documented	Fab Repairs Identified	Fab Repair Trials/ Subcomponent Repairs	Component Repairs	Production Repairs Identified	Flight Qualified Repairs Documented
Intellectual Rights	Concept Documentation	Patent Disclosure Filed	Proprietary Rights Agreements	Data Sharing Rights	Vendor Agreements	Material and Fabrication Contracts	Production Rate Contracts	Vendor Requal Agreements

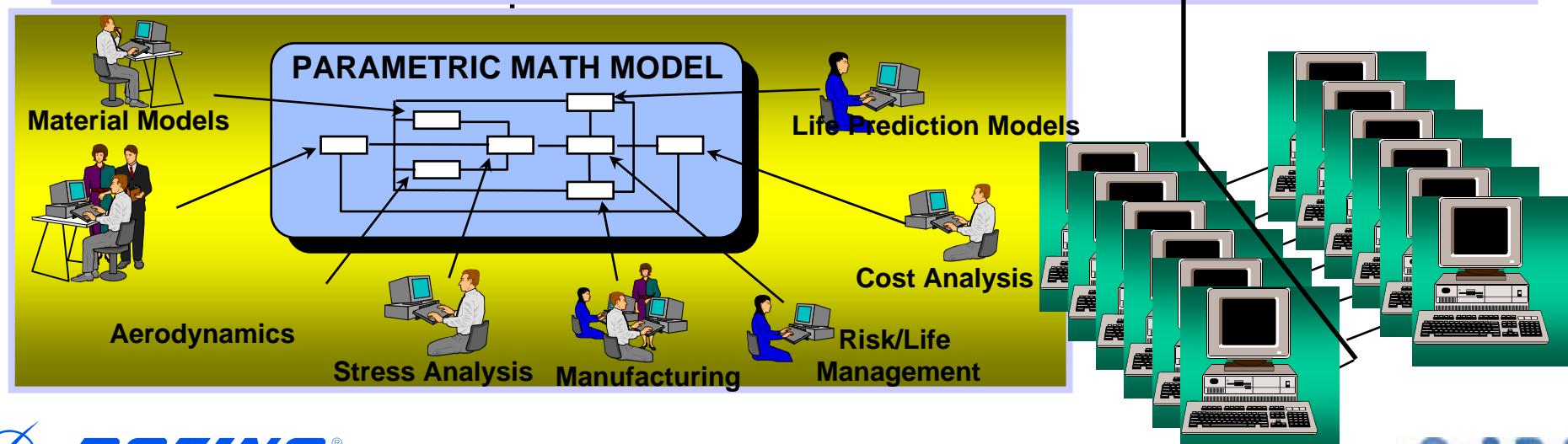
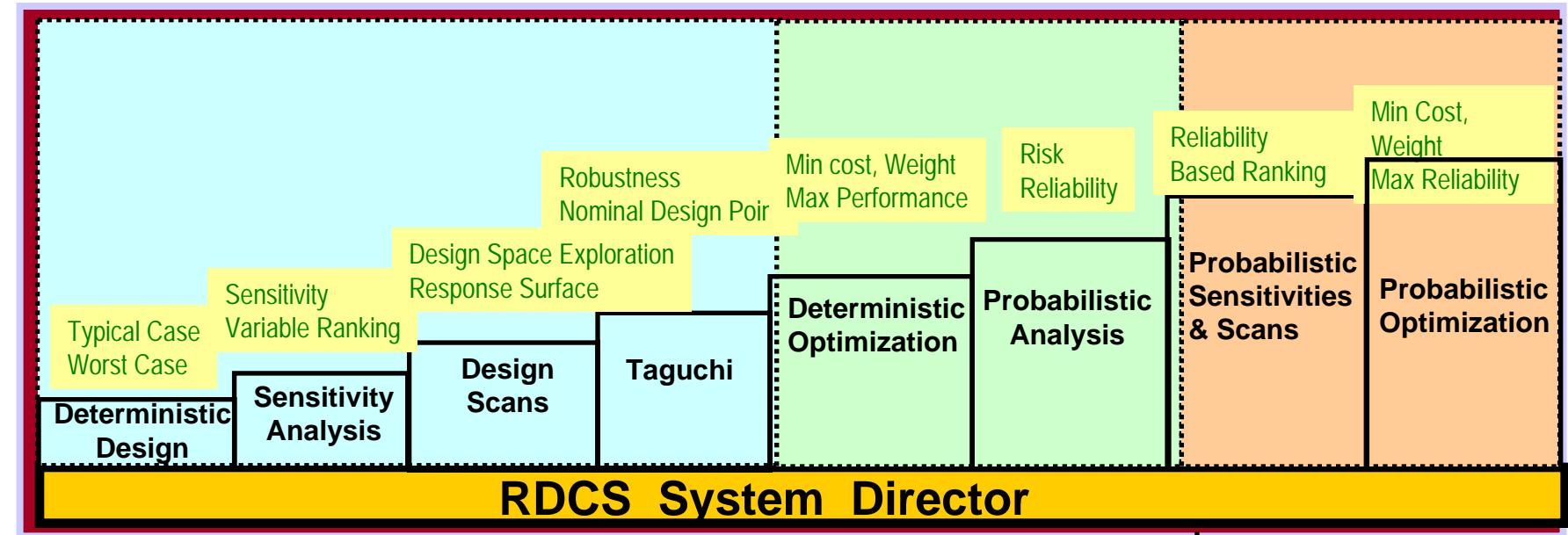




AIM-C System Vision

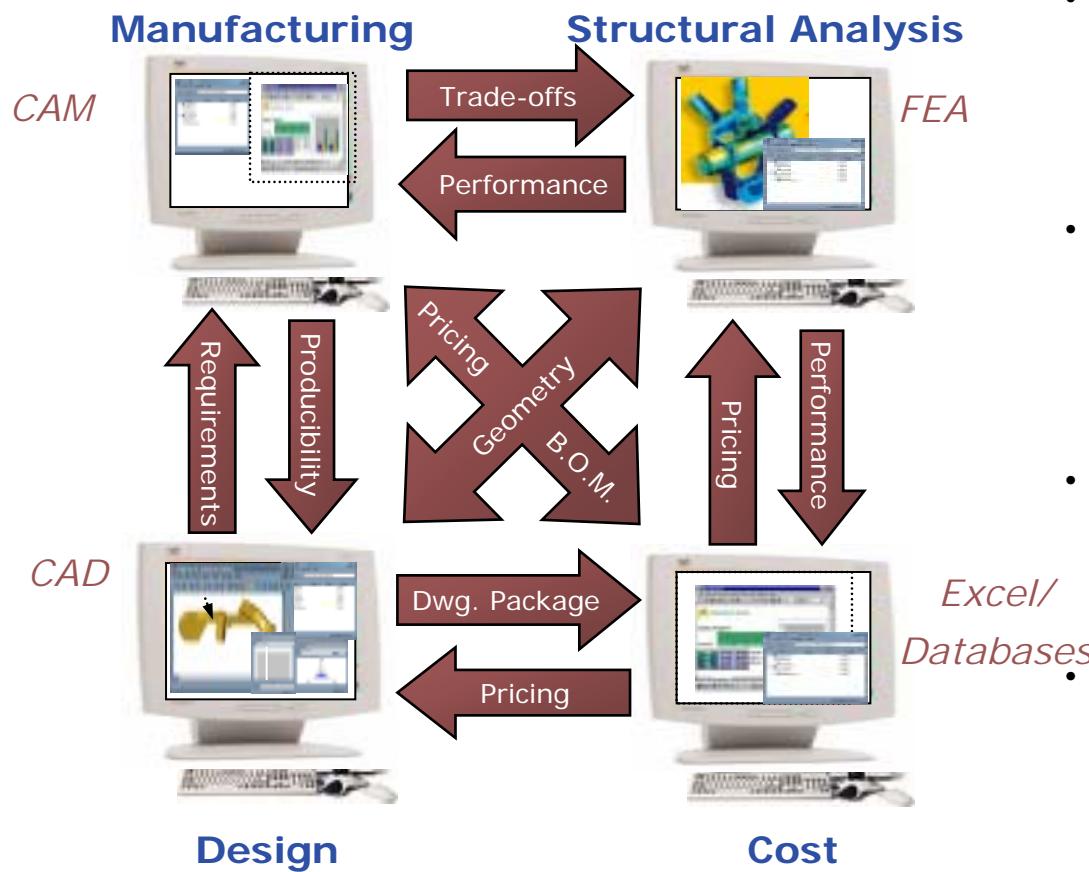


Robust Design Computational System



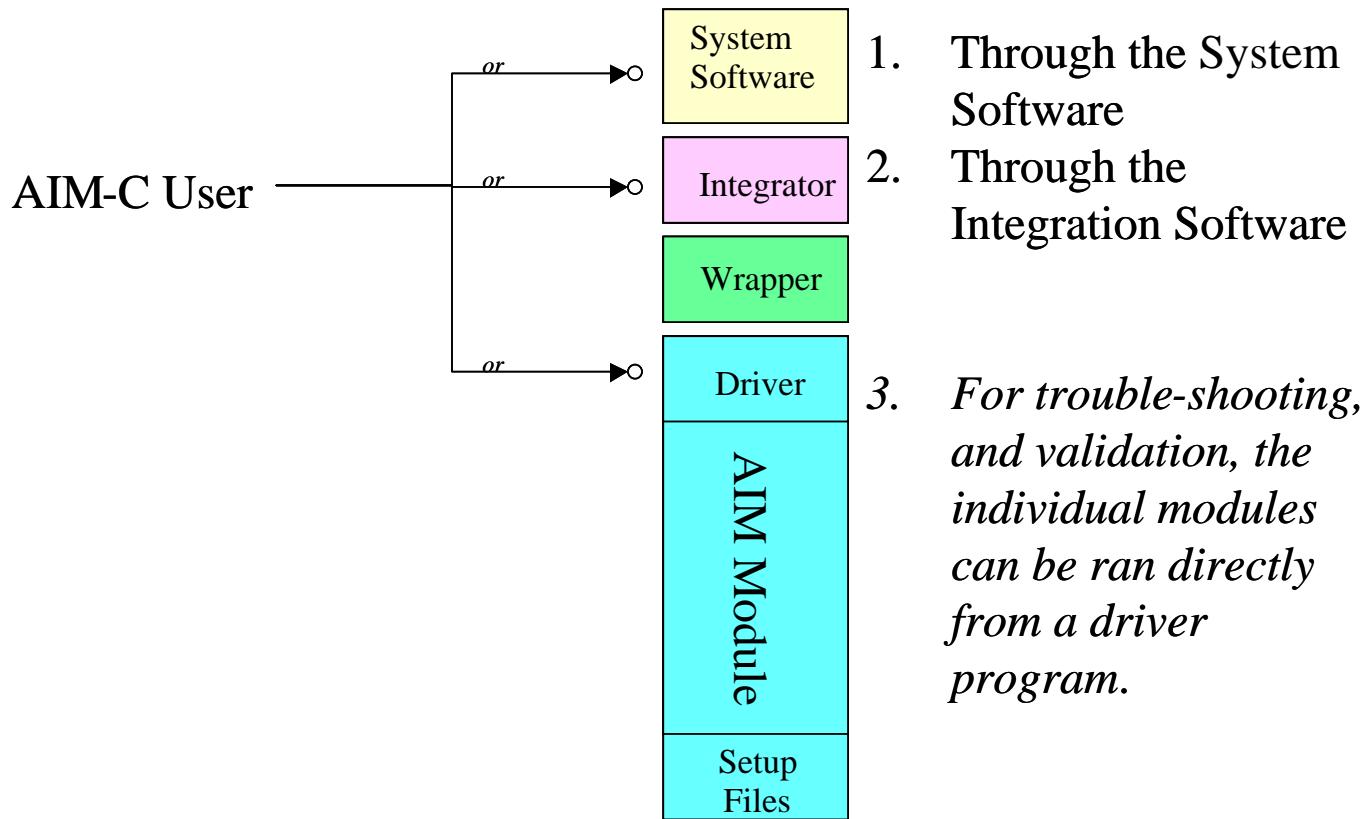
The Oculus Integration System

COTM: A Plug & Play Modeling Environment

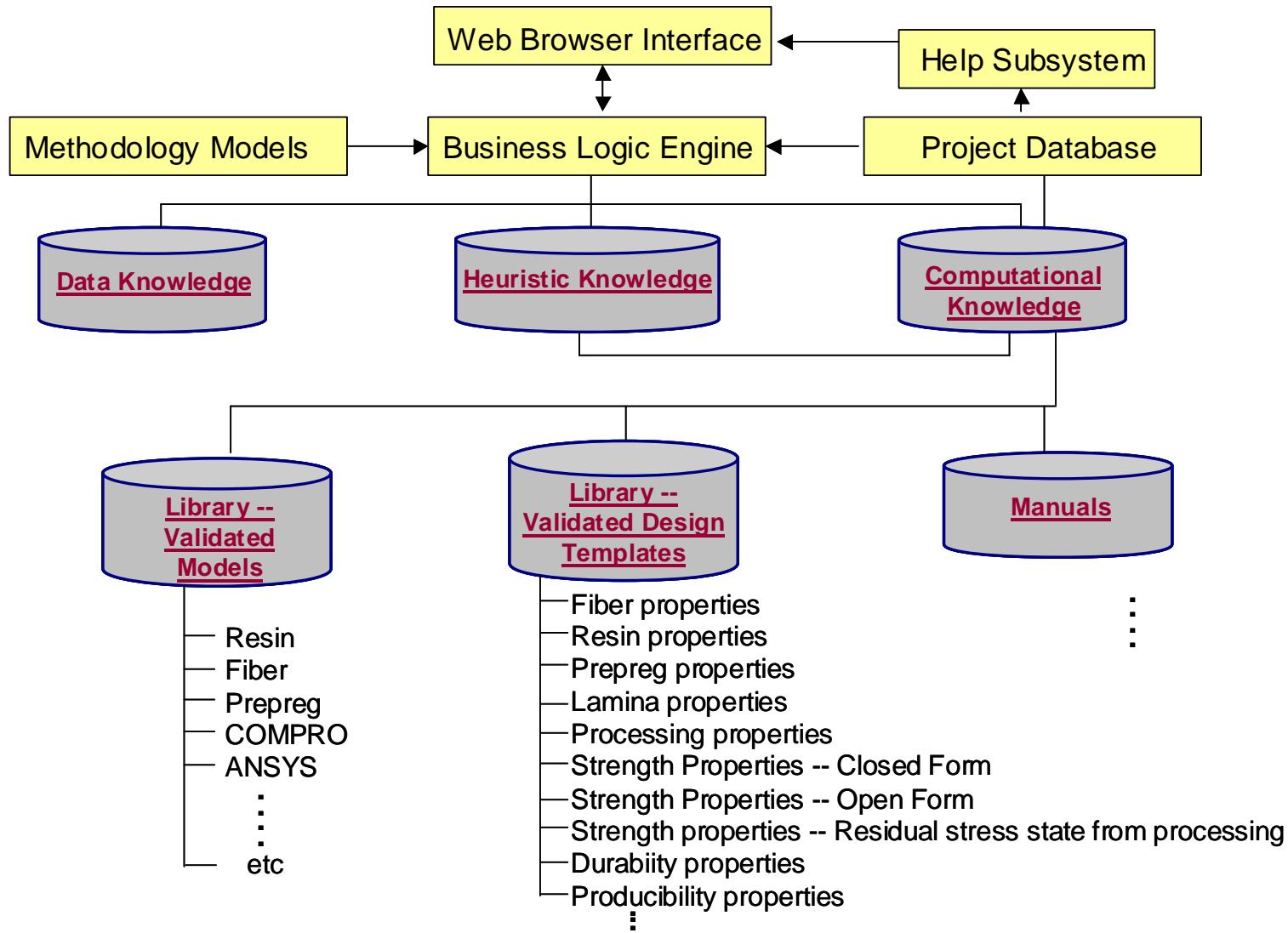


- **Integrates Data and Software Applications on-the-fly**
 - Drag & Drop, Plug & Play
 - Simple to create, modify, manage, maintain
- **Enables Real-time data sharing between applications**
 - Secure
 - Controlled
 - Intra/Internet
- **Platform Independent**
 - Distributed
 - Neutral to Platforms and Applications
- **Increases Value of Previous Investments**
 - Software
 - Hardware
 - Networks

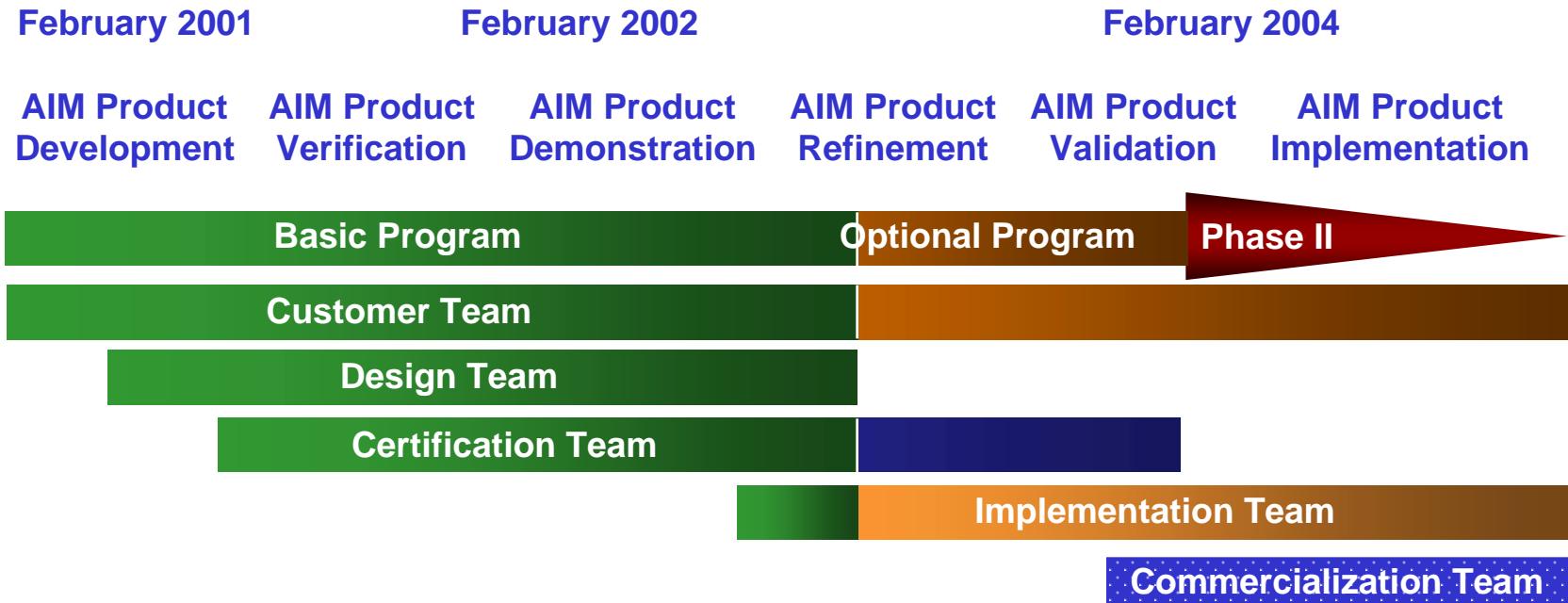
The User Is Able to Run the Module At *Three* Different Levels



AIM-C Software Architecture



AIM-C Transition Plan



Customer Team – To ensure that the product meets the needs of the funding agents

Design Team – To ensure acceptance among users in industry

Certification Team – To ensure acceptance among the certification agents for structures

Implementation Team – To ensure acceptance among the user community

Commercialization Team – To ensure commercial support of users

AIM-C Certification Team



Agency	Integration	Structures	Materials	Producibility
Boeing	Charley Saff	Eric Cregger	Pete George	John Griffith
Navy	Don Polakovics	Dave Barrett	Kathy Nesmith	Steve Claus
Air Force	(Joe Gallagher)	Dick Holzwarth	Katie Thorp	Bob Reifenberg
FAA	Curt Davies	Larry Ilcewicz	David Swartz	Dave Ostrodka
Army	Mark Smith	Jon Schuck	Marc Portanova	N/A
NASA	N/A	Jim Starnes	Tom Gates	Tom Freeman

To Insure That the Methodology, Verification, and System Validation We Do Satisfies Certifying Agencies

Comments and Summary

- Accelerated Insertion of Materials Can be Achieved by
 - Definition of requirements
 - Focus based on insertion needs (design knowledge base)
 - Approach for use of existing Knowledge
 - Validated Analysis tools
 - Focused Testing
 - Feature Based Demonstration
 - Rework Avoidance
 - Knowledge management



Accelerated Insertion of Materials – Composites: *Impact of Manufacturing on Performance*

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Polymer & Composite Material Properties

- Effects of Defects
 - Mechanical effect of common defects
 - Voids, delamination, FOD, wrinkles, impact
- Repair
 - Develop repair materials and processes
 - Demonstrate utility

Product:
Engineering data to support part disposition
Repair specifications and procedures

Polymer & Composite Process Development

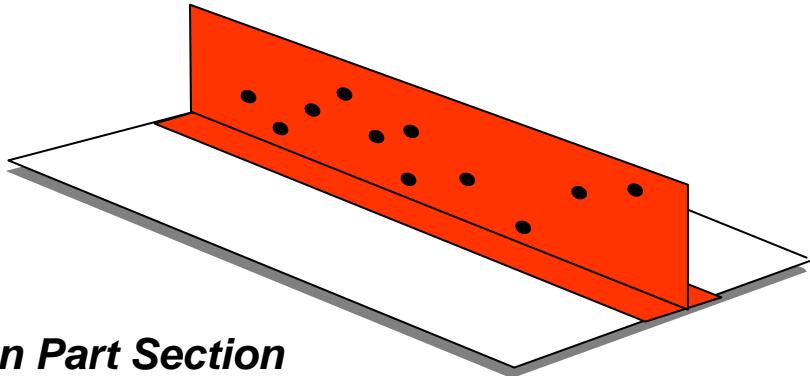
- Define process limits
 - Develop mechanical properties at limit
- Demonstrate reproducibility within the limits
- Define critical steps/tools/equipment
- Develop inspection and QC process

Product: Process specifications

Part Fabrication

- **Elements And Subcomponents**
 - Fabrication of design details
 - Validation of analysis
 - Further definition of inspection and repair requirements
 - Risk reduction for manufacturing and assembly
- **Components**
 - Fabricate actual components
 - Manufacturing demonstration
 - Destructive evaluation
 - Demonstrate repairs
 - Demonstrate component level mechanical performance
 - Validate analysis
 - Demonstrate systems interfaces
 - Demonstrate damage tolerance

Common Manufacturing Insertion Issues

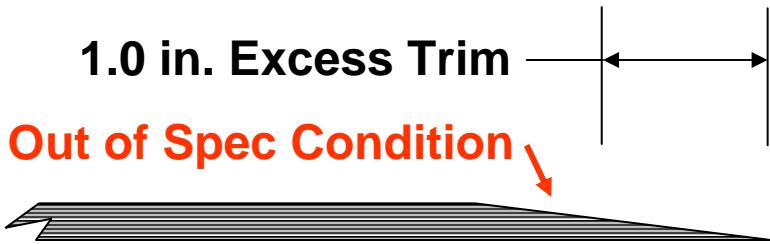


*Thin Part Section
with Cocure Having Voids and Porosity*

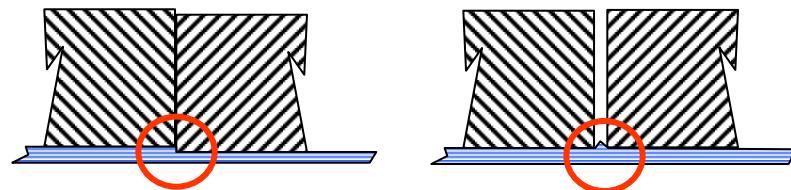
**Process Specification
Calls out $\pm 6-7\%$
Thickness Tolerance**

Thickness Zoning

*Thick Parts Having Large Thickness
Variability (Within Parts and Part-to-Part)*



Edge Thickness Thinning for >1 in.



*Complex Tooling Mismatches
Giving Steps and Puckles*

Common Manufacturing Insertion Issues



**Multiple Material Processing Compatibility
(I.e. Structural Resin and Adhesives)**



***Microcracking in Large, Cocured
Structure (Interactions of Different
Material Cure Requirements and Tooling
Concepts)***



**Process
Specification/
Tooling Incompatibilities for Heat-up
(Invar/Steel)**

Insufficient Out Times



Other Encountered Shop Issues



- **Exotherm of Thick Parts**
- **Thick/Rigid Part Distortion**
- **Incorrectly Compensated Spring-in Angles**
- **Prepreg Tack**
- **Secondary Processing Requirements (Drying, Peel Ply, Sanding, Bonding, Painting, etc.)**



Other Encountered Issues

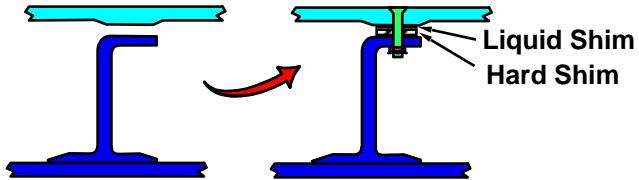


- Resin Solvent Resistance
- Microcracking with Cure, Thermal Cycles, and/or Moisture
- Incompatibility of Resin Characteristics and the Manufacturing Process
- Final Part Accuracy/Repeatability Relative to Tooling Concepts



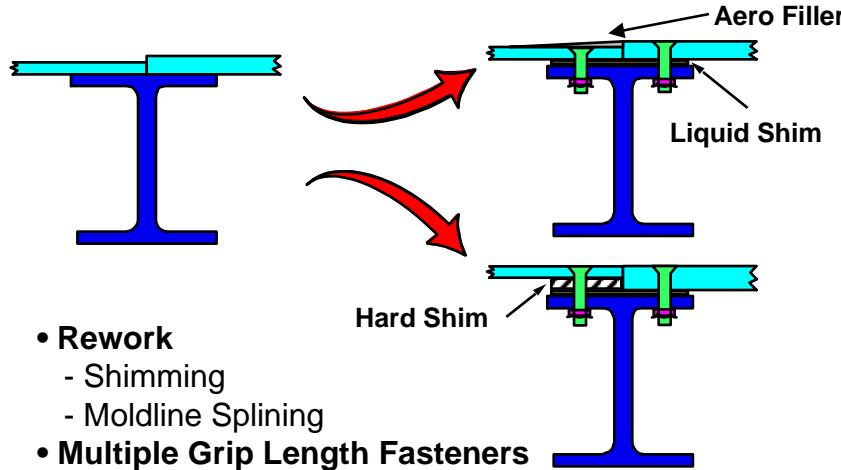
Background

Assembly Variations



- Hard Shim Required for Gaps in Excess of .03 in.
- Engineering Disposition
- Multiple Grip Length Fasteners

Surface Fidelity Variations



- Rework
 - Shimming
 - Moldline Splining
- Multiple Grip Length Fasteners

Major Variation Types

Part Mismatch

- Skin-to-Substructure
- Substructure-to-Substructures

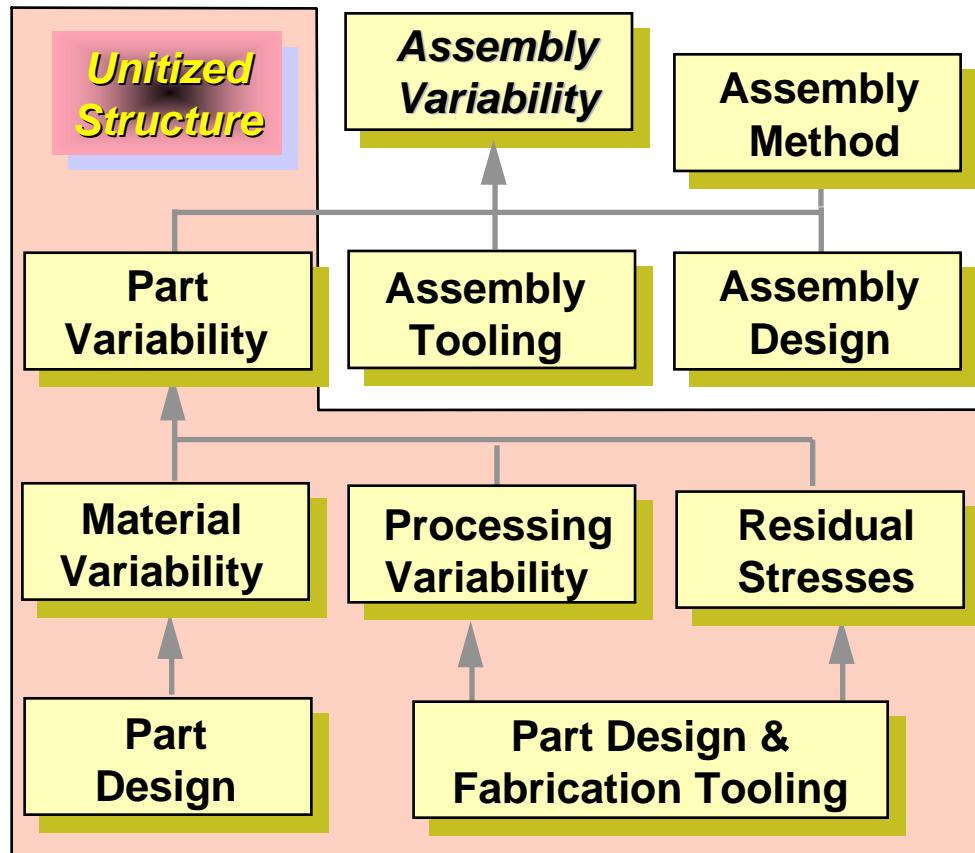
Moldline Fidelity

- Skin-to-Door
- Skin-to-Access Panel
- Skin-to-Skin



Subtask 1 - Root Cause Analysis

Variability Flow Chart

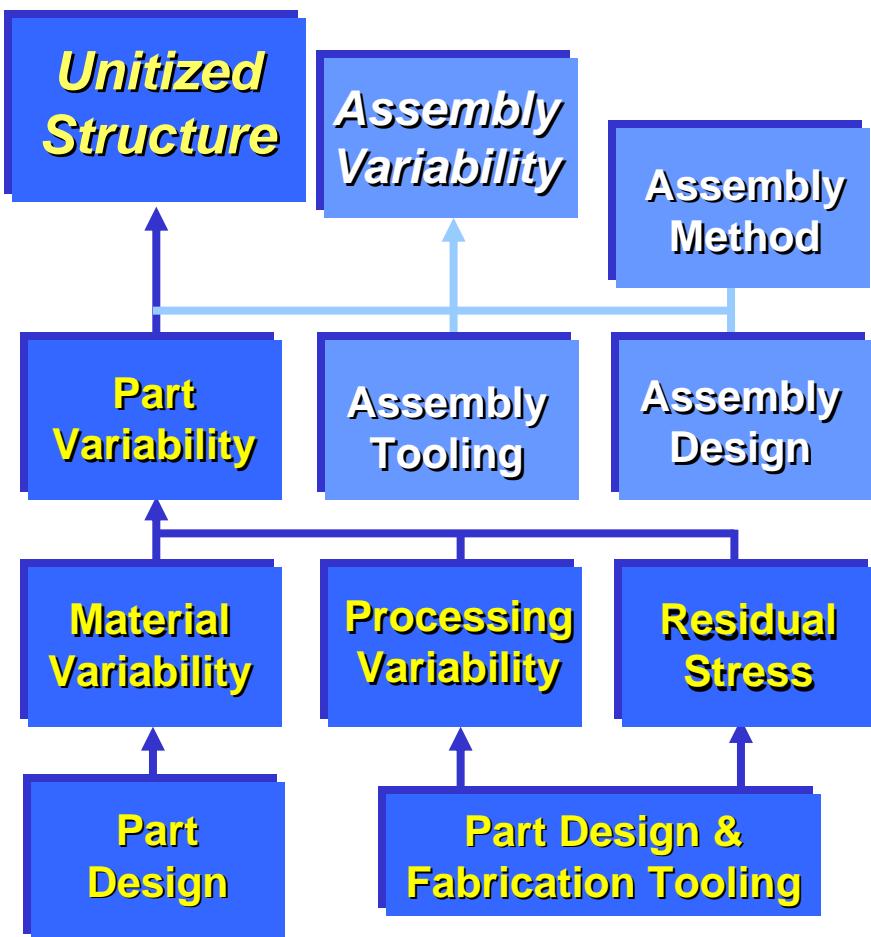


Level	Factor	Item/Cause
Assembly	Assembly Design	Concepts (Piece Parts, Subassembly/Assembly), Length, Width, Thickness
	Part Variability	Materials, Processing, Fabrication Design, Fabrication Tooling, Warpage
	Assembly Tooling	Primary Tool, Details, Accuracy, Repeatability, Tool/Part Coordination
	Assembly Method	Assembly Sequence, Fastener Types, Hole Drilling/Countersinking, Fastener Installation Method
Fabrication	Material Variability	Prepreg, Reinforcement, Resin
	Processing Variability	Cure Pressure, Bagging, Debulking, Out Time, Resin Content
	Residual Stress	Materials, Processing, Tooling, Designs
	Part Design	Length, Width, Thickness, Configuration, Ply Orientations
	Fabrication Tooling	Primary Tool, Caul Sheet, Accuracy, Repeatability, Tool/Part Coordination

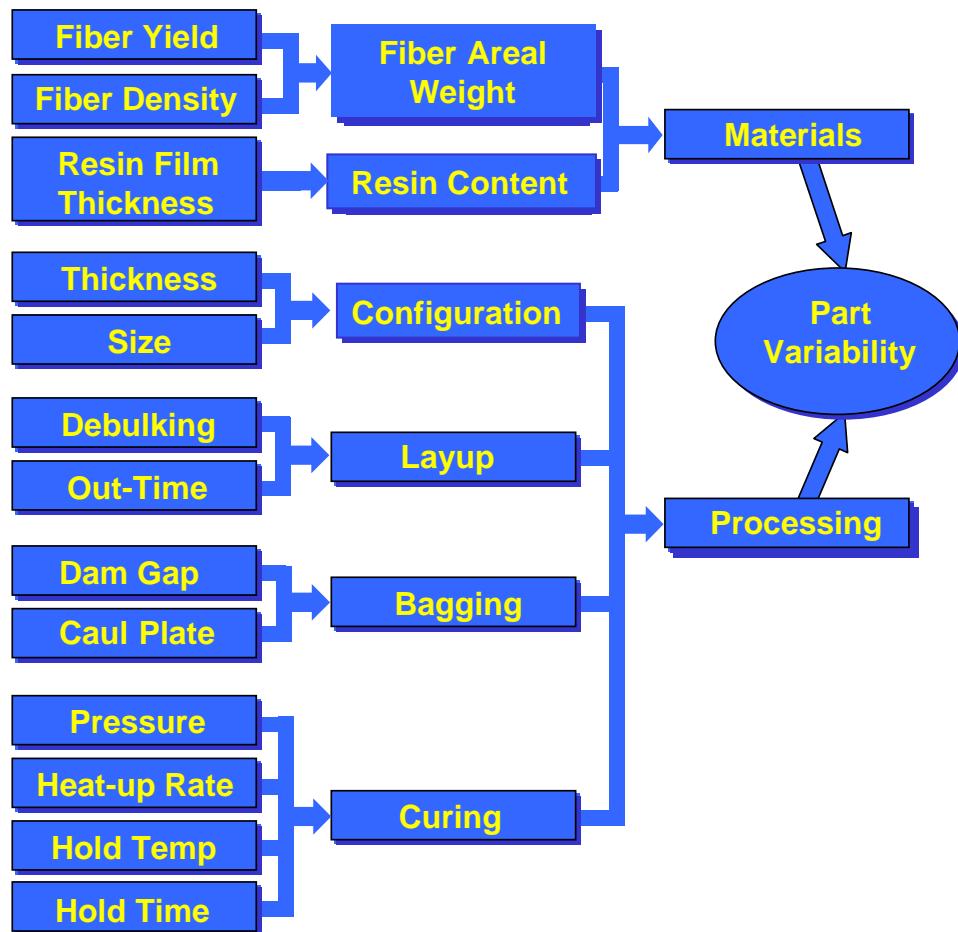


Assembly Variability

Variability Flow Chart



Material and Processing Part Tolerance Accumulations





Part Variability Factors

Design

- Orientation
- Thickness
- Size

Materials

- Unidirectional
- Cloth
- Net Resin
- Excess Resin
- FAW
- Resin Content
- Prepreg
- Manufacturing

Processing

- Material Out Time
- Bleeder
- Inner Bag Perforations
- Dam Gaps
- Dam Type
- Debulking

Cure

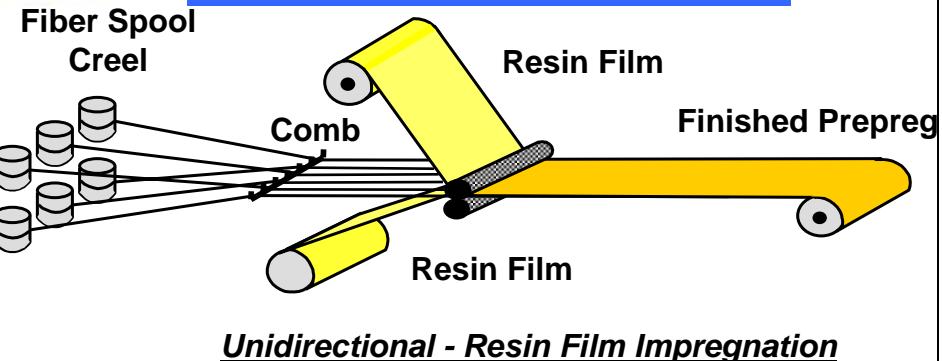
- Pressure
- Vacuum
- Heating Rate
- Hold Temp
- Hold Times

Tooling

- Caul Plate

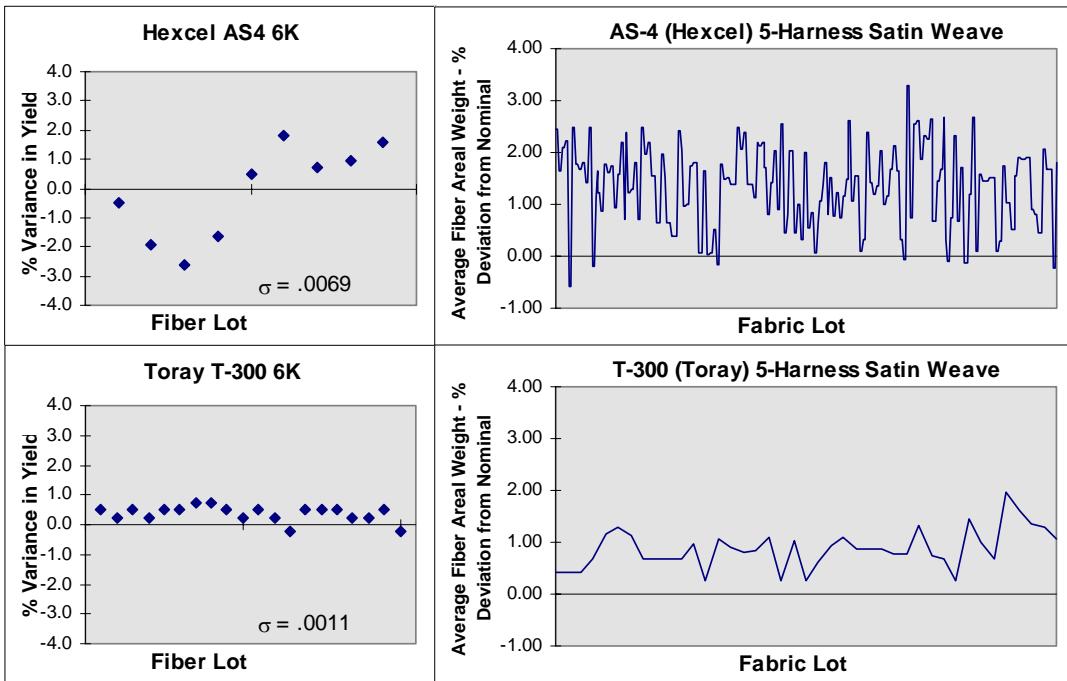


Material Variability

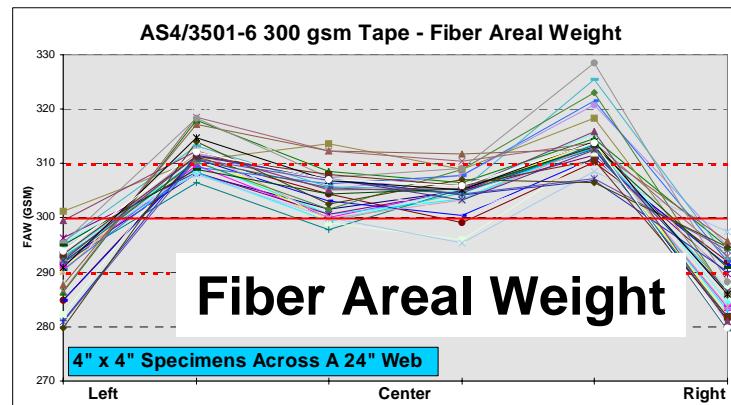
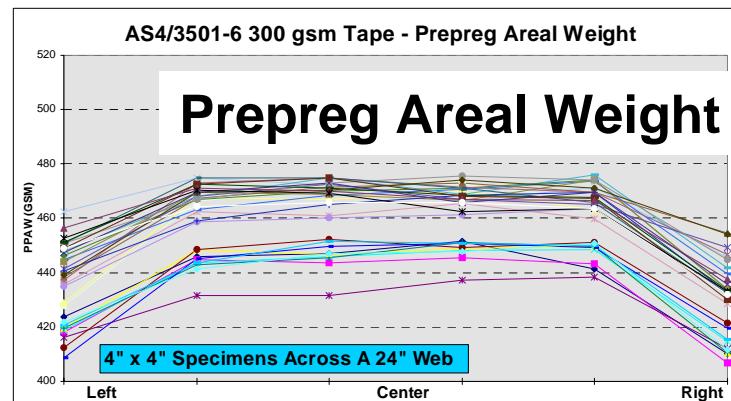


Unidirectional - Resin Film Impregnation

Fiber Variability (210 Batches)



Prepreg Variability (21 Batches)



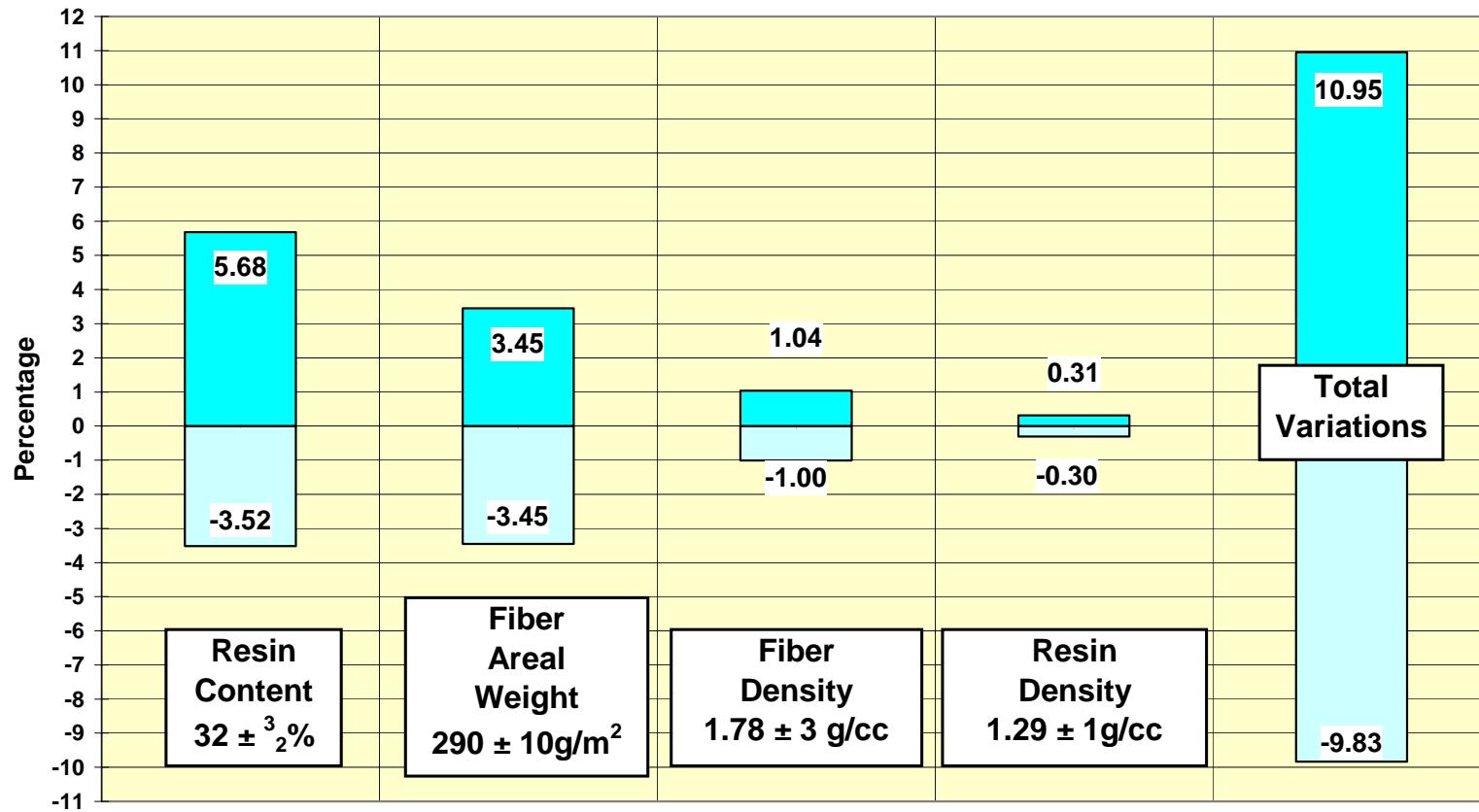
- Fiber Yield Variation Translates to Fiber Areal Weight Variation (Cloth)
- Prepreg Variation is Driven By Fiber Areal Weight Variation



Material Variability

Theoretical Prepreg Variability

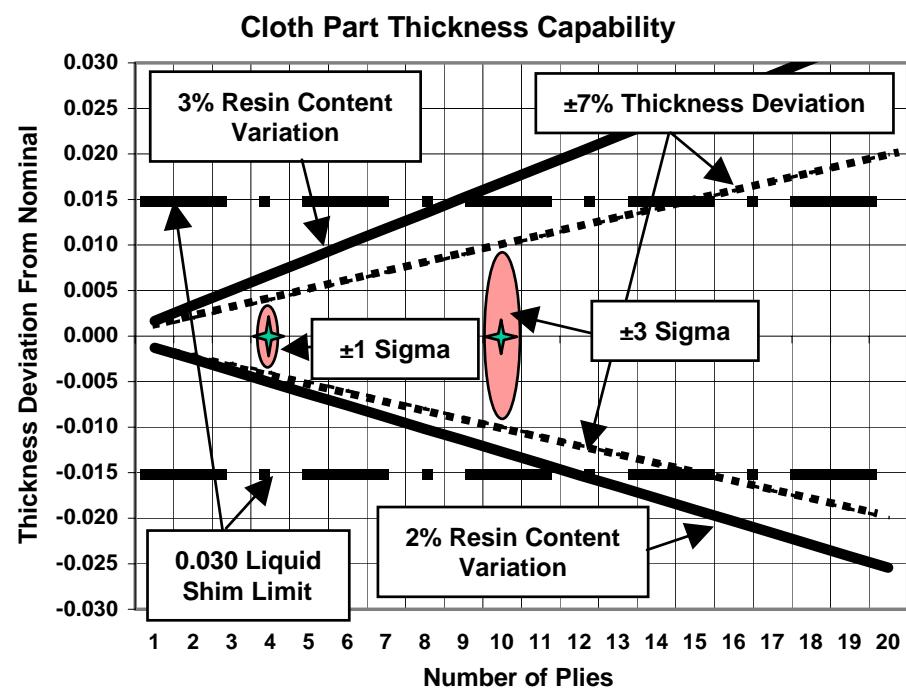
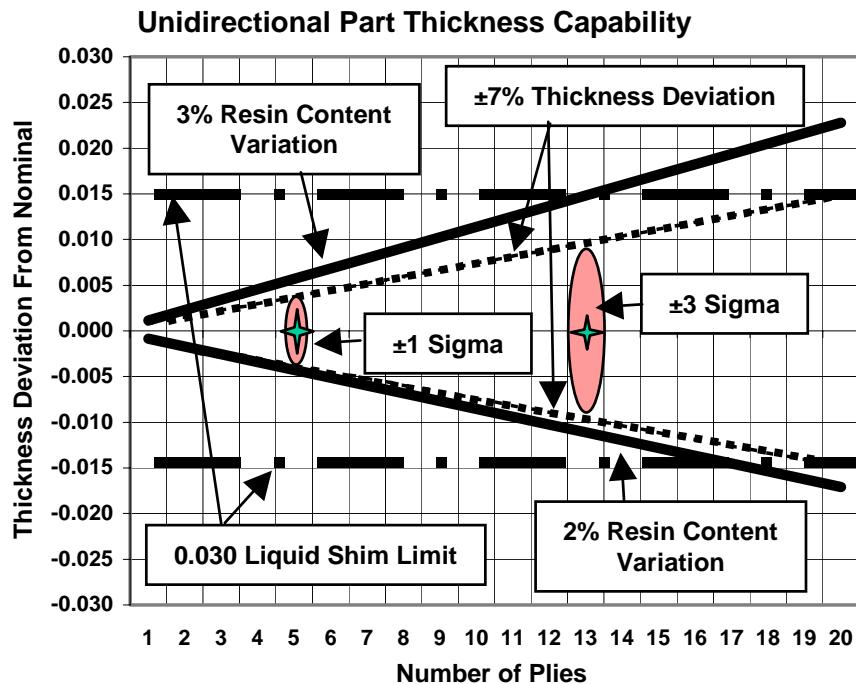
Prepreg Variability Contributing Factors
IM7/977-3 Unidirectional, Net Resin
(per Material Specification Limits)





Material Variability - Process Capability

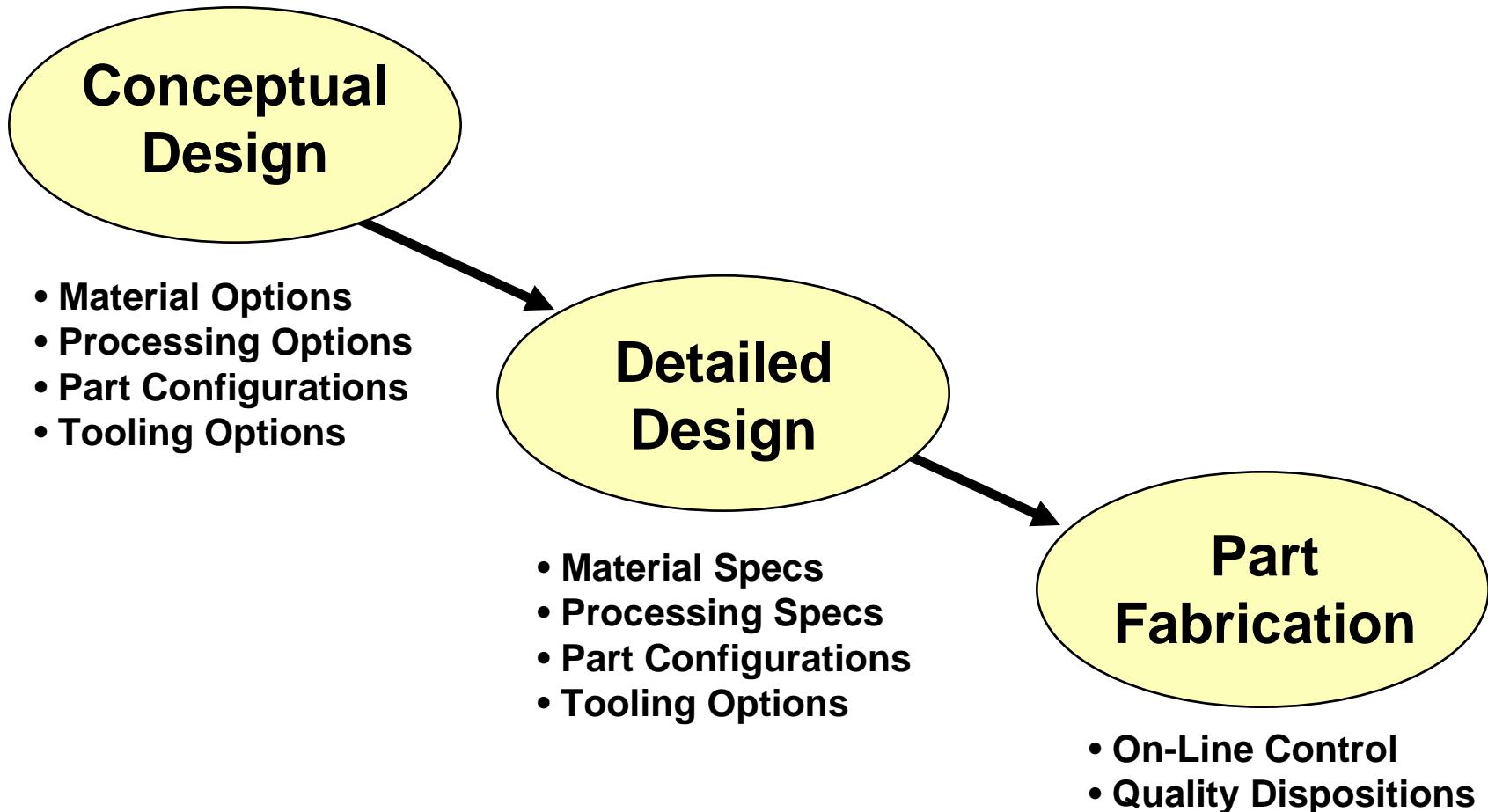
± 1 and ± 3 Sigma Process Capability for Thickness



*The Probability of Consistently
Achieving $\pm 7\%$ Desired Part Thickness is Very Low!*

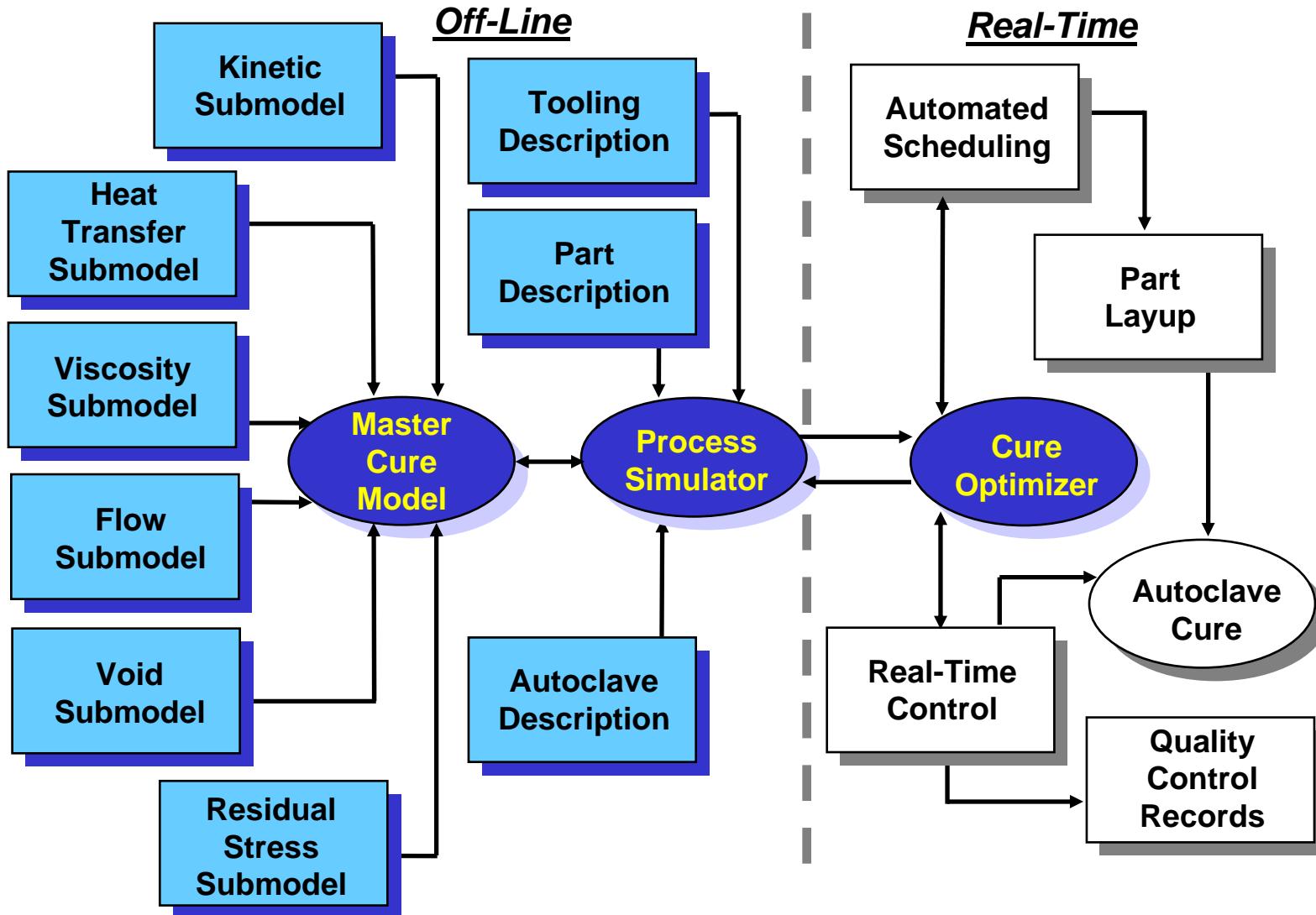


Primary Model Usage

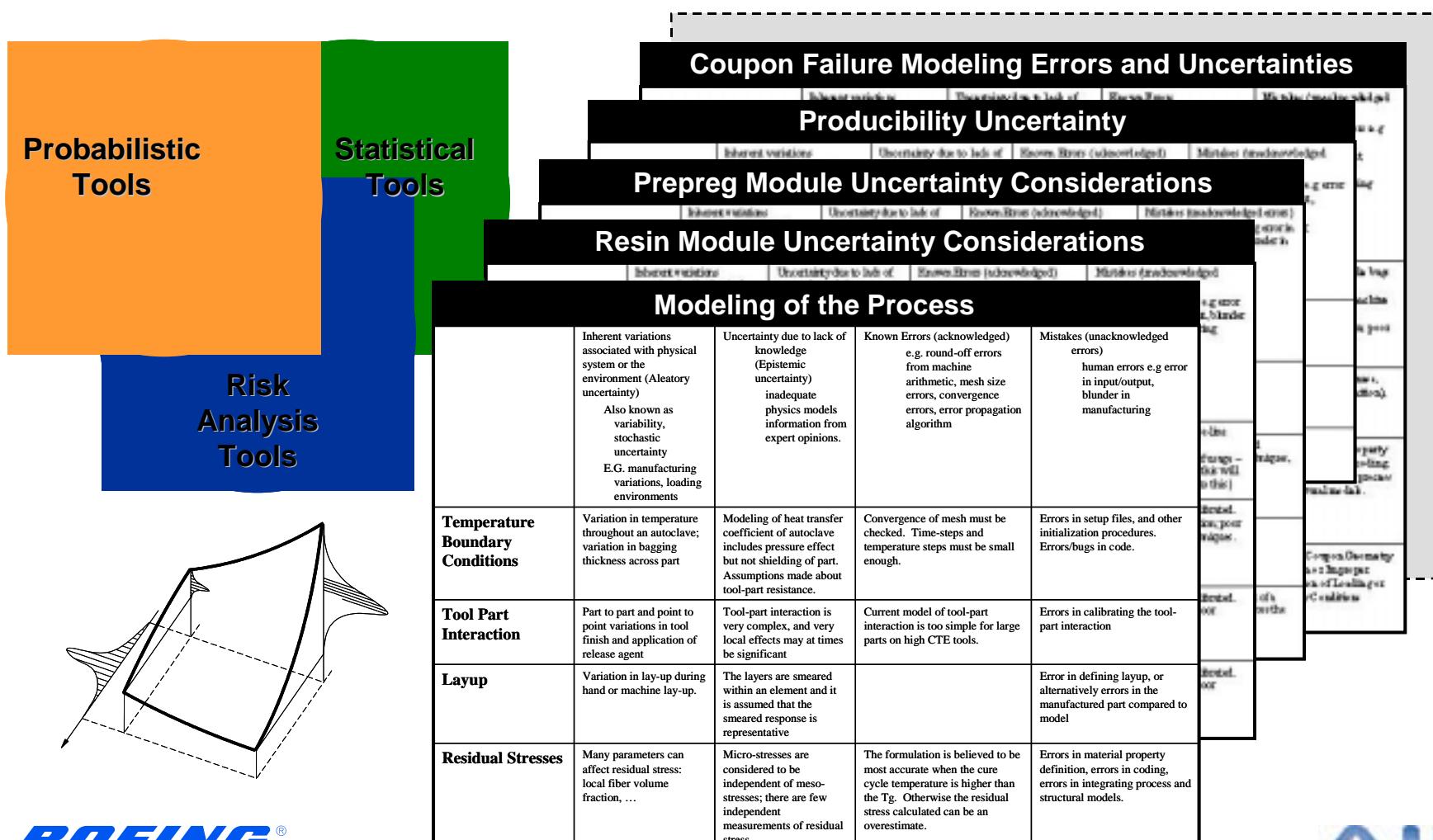




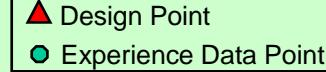
CACC Cure Process Modeling



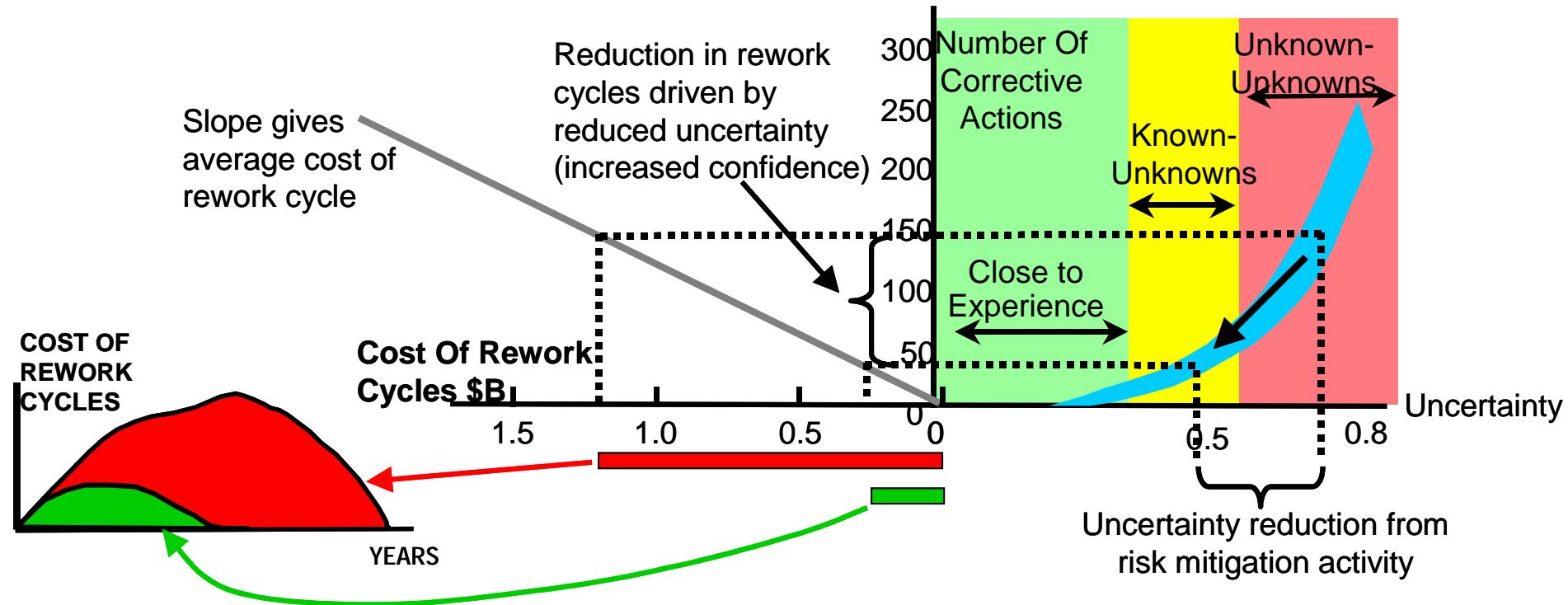
Understanding Uncertainty – The Benefit of Linked Simulation Tools and Methodology



AIM-C Methodology Impact on Traditional Qualification

Structures Maturity	Non Structural Applications	Secondary Structural Applications	Primary Structural Applications					
AIM-C Application	AIM-C System Run to Identify Critical Factors for Analysis, Test, Demonstration To Fill Screening Database Requirements	AIM-C System Run to Define Preliminary Design Database Requirements	AIM-C System Run to Define Design Database Requirements For a Desired Confidence Level	AIM-C System Run to Define Remaining Design Database Requirements				
	Screening Database Exists Broad Range of Data Limited Replications	Preliminary Design Database Exists Full Distribution on Few Key Properties	Allowables Database Exists Full Distribution on Key Properties	Production Readiness Established and System Validated with Confidence Metrics				
TRL	1	2	3	4	5	6	7	8+
Confidence Lvl	10%	20%	30%	40%	50%	60%	70%	80%+
Criteria-Based Assessment								
Quantitative Assessment via Distance From Experience								
		Ages are the "drivers" for this application			Distance from experience ("similar" hardware, building block tests, and/or anchor points for models) measured using "anchored" models			

AIM-C Reduces Time and Cost of Insertion through Orchestration of Knowledge, Analysis, and Test



Conclusions

- It is vital to work as a team - customers, suppliers, integrator, certifier. *Any constituent can be holding the critical link to insertion.*
- An approach or methodology serves as an alignment tool to the team.
- Look at the full picture to devise focused plan. Ask *all* questions and fill in as appropriate from knowledge, analysis, and test.
- Don't forget that it is not an "ideal" world. Plan for robustness.
- Demonstrate and validate success.